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FOR THE SOLAR CORONA"

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"NEUTRONS AS AN ENERGY SOURCE FOR THE SOLAR CORONA"

Fowler and Hashemi[1] have recently hypothesized a coronal heating mechanism, which depends on the radioactive decay in the corona of neutrons produced in the photosphere, with the subsequent energy loss of the charged decay fragments. We wish to point out that the existence of a photospheric neutron flux, of the magnitude hypothesized, would be detectable through observation of a flux of 2.22 MeV neutron-proton capture gamma rays, emanating from the outer $\sim$20 gms/cm^2 of the photosphere. We will show that the expected capture gamma ray flux based on the model[1] in question is several orders of magnitude larger than current experimental findings on the continuous and sporadic emission of the 2.22 MeV gamma ray line from the Sun would indicate.

The basic neutron producing reaction assumed by Fowler and Hashemi[1] is $^2H(d,n)^3He$, which yields neutrons with 2.4 MeV kinetic energy. In order to slow down to the 5 keV energy required for their coronal model, the neutrons must pass through about 2 gm/ cm^2 of hydrogen in the photosphere.

This condition would put the source of the DD neutrons at a depth of $\sim$350 km below the photosphere, where the temperature[2] is $\sim$8300°K, the hydrogen density[2] is $\sim 1.5 \times 10^{17}$ and the D/H concentration ratio[1] may be as large as 2×10^{-4}. The nuclear reactions are presumed to be non-thermal with the deuterons accelerated in numerous pinch effect instabilities occuring just under the photosphere. This mechanism is analogous to the process producing neutrons in linear pinches observed in the controlled thermonuclear research program[3]. Fowler and Hashemi[1] have calculated a total neutron flux input of 1.7×10^{11} neutrons $cm^{-2}s^{-1}$ into the base of the corona, by balancing the total energy lost by the corona(at 1 A.U.) with the total energy input at the base of the corona from the neutron decay energy. This leads the authors[1] then to a total (essentially continuous) emission rate from the Sun of $\sim 10^{34}$ neutrons/s.

In order to estimate the capture gamma ray flux expected, we will consider an idealized geometry in which a source layer of thickness δt, located just under the photospheric edge, is ejecting neutrons of energy E_0(2.4 MeV) at a rate $Q(E_0)$ $cm^{-3}s$ uniformly around the Sun. The neutron flux per unit energy due to the source Q is $\phi(E) = Q/E\ \Sigma_s(E)\ (cm^{-2}s^{-1}MeV^{-1})$, where E is the neutron energy after some number of scatterings and $\Sigma_s(E) = \bar{n}\sigma_s$ is the energy dependent macroscopic neutron scattering cross section for hydrogen. This expression is given by Amaldi and Fermi[4] for the case of no capture. However, for hydrogen the capture cross section is always very small compared to the scattering cross section, even at thermal energies, so that the above spectrum may be used for calculating the capture rate or equivalently the 2.22 MeV gamma ray production rate. The capture rate (R_c) for the neutrons traveling deeper into the photosphere may be expressed approximately as

$$R_c \cong 2\pi R_\odot^2 \int_{E_{th}}^{E_0} \phi(E)\sigma_{cap}(E)\overline{nt}\ dE\ (s^{-1})$$

where $\sigma_{cap}(E) = k'E^{-1/2}$ is the neutron capture cross section for neutrons incident on protons at energy E, $\overline{nt}$ is the average number of hydrogen nuclei encountered per cm^2 after traversing a distance t below the source layer, and $R_\odot$ is the solar radius. E_{th} is the average kinetic energy per particle corresponding to the temperature of the medium in which the capture takes place, or 8300°K in this case. This expression may be reduced to

$$R_c \cong 5 \times 10^{33} \frac{k'}{\sigma_s\ \delta t} \frac{\overline{nt}}{\bar{n}} \int_{E_{th}}^{E_0} E^{-3/2} dE\ (s^{-1})$$

using the previously defined quantities and the condition that $4\pi R_{\odot}^{2}\delta t Q \cong 10^{34}$ neutrons s^{-1}. Taking $\overline{nt}/\overline{n} = 7.7 \times 10^{7}$cm as the effective depth into the photosphere from which the capture gamma rays will contribute to a flux at the Earth (corresponding to an absorption mean free path of 20 gms/cm^2 in H for 2.2 MeV photons), $\overline{n} \cong 1.5 \times 10^{17}$ hydrogen nuclei cm^{-3} and $\delta t = 1.6 \times 10^{5}$cm (cf. Fowler and Hashemi[1] for a pinch effect compression factor of 16), gives a capture gamma ray flux at the Earth of the order $10^{6} - 10^{7}$ photons $cm^{-2}s^{-1}$. No decay loss correction is needed for this estimate, since the mean time for neutron capture in hydrogen at the density indicated is $\sim$100 s compared to the decay mean life time of $\sim$1000 s.

From current experiments[5], the continuous emission of this gamma ray line from the Sun is given at a limiting flux of $\sim 10^{-3} \rightarrow 10^{-2}$ photons $cm^{-2}s^{-1}$. Even though neutrons are without doubt produced copiously in nuclear reactions near the solar surface when sufficiently energetic particles are present, it is doubtful they play a significant role in the energy input into the chromosphere and the corona. Audouze[6] has recently commented on this neutron model of the corona on other grounds.

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